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Designing a spatial planning support system for rapid building damage survey after an earthquake: The case of Bogota D.C., Colombia

ABSTRACT

Damage assessment determines the safe condition of houses and buildings that were affected in a disaster. These elements must be inspected to determine if they can be occupied by people. The objective of the present research is to design a model for the planning of a rapid building damage survey after an earthquake and manage the spatial information collected. The model is built on by three sub-models aiming to estimate the number of trained people required, their spatial allocation and the right information flow. Nevertheless, the present paper only puts forward the second sub-model related to the allocation of the service areas to the building inspectors, due to the degree of development reached and the contribution represented by this. To allocate the trained people, five methods were applied: *average number of parcels or blocks*, *euclidean allocation*, *multiple-ring-buffer, network analysis (service area), and route allocation*. Aditionally, the use of the *CommunityViz* a GIS application as spatial planning support system (SPSS) is tested as a tool in the planning of the emergency response to determine the priority areas to be inspected after the earthquake. The allocation method is selected according to the data and the preparedness level that every city has, but the highest level of accuracy comes from the *route allocation* method. The use of *CommunityViz,* in the present research allows to the decision makers observe four priority attention scenarios according to different weights to the factors such as density population, degree of damage, density of built-up area, probability of secondary effects and availability of the inspectors. The use of *route allocation* method will increase the effectiveness of the inspection task, and in spite of the use of CommunityViz to plan the emergency response is feasible, its utilization is still limited due to the time that every analysis requires and its limitation in large scale problems.

Keywords: Building damage survey, service areas, route allocation, spatial planning support system and priority attention scenarios.

1. INTRODUCTION

Damage assessment is a methodological procedure to determine quantitative and qualitative the effects of the disasters. The main purpose is to have informed-decisions in the emergency, recovery, replacement and developmental reconstruction state.

The present research is concentrated on the damage assessment of private houses and buildings, because building damage survey is a collective consumption service provided by the goverment as a way to ensure that all citizens are living or staying in safe places after an earthquake, in the case of aftershocks.

In Bogota, the District Office of Emergency Prevention and Management (DPAE), has been working on the project about strengthening the response capacity against a big earthquake, since 2003. Hence, the Colombian Association of Seismic Engineering (AIS) was hired to develop a methodology and also a manual which has guidelines, for inspecting buildings after an earthquake. DPAE has been training architects, engineers and student in these areas since 2002 until 2003 and again since 2007 until now. Nevertheless, it is important to say that in spite of the presence of trained people for building inspection after an earthquake, the effectiveness of the methodology in a real operation has not been tested yet.

Additionally, DPAE contracted the Andes University (ULA) to undertake *The risk and loss study scenarios after an earthquake in Bogota D.C.* (CEDERI, 2005), which aimed at estimating the number of affected houses in every return period[1] and consequently the likely number of trained people required. The study considered seven loss estimation scenarios but the present research considers the scenarios when the seismic source is the falla frontal de la Cordillera Oriental in the return periods (rp) of 250, 500 and 1000 years.

Rapid building damage survey is a service that will be provided in an emergency state and it must be supplied to all people who own a house under the same conditions, according to the

[1] Return period is the average time span between large earthquakes at a particular site.

theory of public goods (Samuelson, 1954;Pacione, 2005). The provision of this service should be allocated according to need for the welfare of the society (Pacione, 2005), which is in this particular case, the safety of the individuals. This research is concentrated on the rapid survey, because it is oriented to save lives in short period, stopping people continue living in unsafe buildings. But this activity requires to be modelled in order to be effective and efficient, because according to Benini and Conley (2007, p. 1) “rapid assessment is one of the standard informational tools in humanitarian response and is thought to contribute to rational decision-making”.

Rapid building damage survey is a service that must be allocated according to spatial decision support system based on a model which combines equity and efficiency, taking into account policies which set up priorities. The planning process is an activity of the preparedness phase that must be done because the event could happen in 20 years or tomorrow, and carried out this process under the conditions immediately after an earthquake is not suitable and the risk of losing lives will increase. Planning and feedback are significant ingredients of an effective relief and rehabilitation program (Debarati Guha-Sapir, 1986).

Research about decision support system for resource allocation in emergency response is invariably focussed on: search and rescue (SAR), stabilizing work (e.g. dam failures, fire, etc.) and immediate restoration of the transportation lifelines (Fiedrich, Gehbauer, & Rickers, 2000); schedule for the restoration of the transport lifelines (Yan & Shih, 2007); traffic assignment and departure schedule decisions for multiple priority group (the elderly, hospital patients, etc.) (Chiu & Zheng, 2007); demand, supplies and vehicle availability (Ozdamar, Ekinci, & Kucukyazici, 2004); vehicle routing problem (VRP) or in pedestrian evacuation and rescue within micro scale urban indoors spaces or areas (Lee, 2007); access to emergency shelters (Melanie, 2004); even, in the logistical domain has been studied guided decisions to deliver relief to affected communities (Benini, Conley, Dittemore, & Waksman, 2008).

Nevertheless, few of them has tackle the problem of allocating resources for carrying out a building damage survey after an earthquake, in any of its modalities and in which there is a combination of two classes of resources: people and material. The resources must be ideally distributed with equity which is feasible in the case of the material resources, but not in the domain of people (human resources), because they are located according to the lifestyle and it is likely that they do not live in the most vulnerable areas. In this case, it is therefore necessary to address the problem between the logistics of moving personnel and the need of the situations.

2. LITERATURE REVIEW

The first step in a mitigation, preparedness or response planning process is to identify the hazards, which affects some areas. A hazard is a potential occurrence of a physical phenomenon of natural, socio-natural or anthropogenic origin which might affect in a negative way people, infrastructure and economy. The second step is to make the vulnerability evaluation, which is the process to estimate the susceptibility to a damage that the element at risk (e.g. population, built-up areas, infrastructure, etc.) have when a physical phenomenon struck them. The third, and last step is the risk assessment. The risk is the result of hazard multiplied by vulnerability and by the amount of elements at risk.

The loss estimation is a technique to estimate the potential losses from earthquakes and key elements to be integrated in the management and development of megacities (Bendimerad, 2001). The loss estimation scenarios mentioned in the introduction, are tools of the risk assessment, and authors as Hoard et al. (2005) state that emergency planners or decision-makers must be able to develop a range of scenarios, in order to plan for each, and formulate best practices that apply for all of them. This approach allow to include priority training programs and develop skills like time management, cognitive mapping mediation and team management, as well as the ability to make decisions under stress (Fuad Aleskerov, 2005).

The rapid building damage survey is concentrated on saving lives through making a brief evaluation of the habitable condition of the buildings, and it must be done in a period of maximum three days, according to the international standards.

Countries such as United States, Mexico, Japan, Colombia and Macedonia (Kiril and Metodij university, former Yugoslavia) have designed techniques to collect information after earthquakes and the first three have considered a rapid building damage survey and detailed instead of a general building damage survey (Contreras, 2002).

As it was observed in the introduction, the building damage survey after an earthquake is an activity that requires to be modelled; hence, the use of scenarios in the present research because they are a result of combination of: modelling and planning. Planning is a process, to reach decisions to achieve certain goals within the available resources, and one of the decision issues is how to allocate resources. There are several models aim to allocate resources for any emergency response, which authors as Batanovic, Petrovic and Petrovic (2009) classified as *general, approximate solutions and stochastic/fuzzy* and *anti-covering models*. While, other authors as

Benini et al. (2008) have concentrated on developing statistical models to evaluate the effectiveness and efficiency of the resource allocation related to delivery of relief goods.

People have to tackle natural and man-made events that sometimes have a high cost in lives and properties besides the indirect losses. Because of their scale and magnitude, the government needs to address their impact, and prevent or mitigate them. Due to the information plays an increasing significance in the mentioned effort (Wallace & Balogh, 1985), authors as Perry and Liddell (2003) assert that the effectiveness of emergency planning can be reduced by the wrong allocation of resources or an improper management of the information.

3. METHODOLOGY

The aim of this research is to design a process model for the planning of a rapid building damage survey after an earthquake, and to manage the spatial information collected. The basic model which involves all the elements relative to the estimation of the number of trained people required, resource allocation for emergency response and information management is illustrated in figure 3-1.

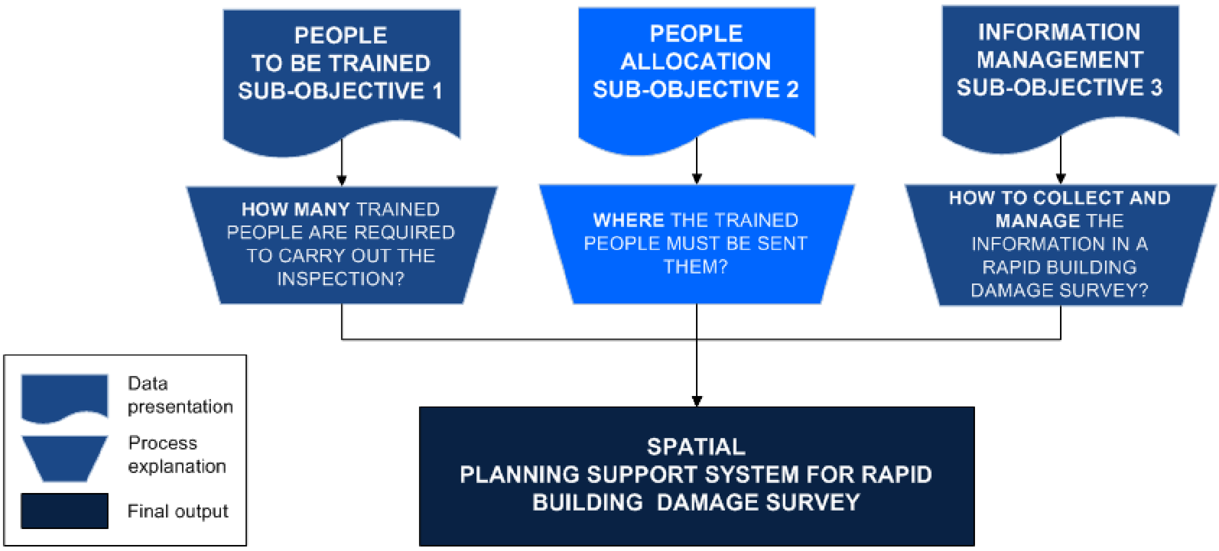

Figure 3-1 Basic model

However, as it was stated before, the present paper is going to be focus on the second sub-model which correspond to sub-objective 2; therefore, the methodology presented in this paper will be correspond to this part of the research.

The model to be developed aims to create service areas, defined as the inspection areas made up by a certain number of parcels assigned to every inspector in the period of the rapid building damage survey. The main purpose is make an efficient distribution of the resources and the work load between them, in this particular case, the resources are trained people or building inspectors and the idea is to avoid uncovered areas and visit houses twice.

It is assumed that inspectors will be at home for the time of an earthquake. The model is developed in the next steps: first, geocode trained people; second, estimate likely availability of the trained people after an earthquake by comparing their location with the areas with a high degree of damage or a high number of injuries and casualties, according to loss scenarios; and third, estimate service areas. According to the availability of the data and the accuracy level that decision makers or emergency response planners require, it is necessary to use different methods to estimate the service areas. The accuracy level is understood in the present research as the number of parcels grouped in a service area by the application of this model, and the number of parcels that can be inspected in the reality. This second model is presented on figure 3-2.

The methods considered by the present research to allocate the service areas to the building inspectors or trained people are: *average number of parcels or blocks, euclidean allocation, multiple-ring-buffer, network analysis (service area), and route allocation*. All of them will be explained in the next sections.

Average number of parcels or blocks to inspect: the total number of parcels to inspect in every return period is divided in three (the standard time to carry out the rapid building damage survey), to know how many parcels must be inspected per day. The number obtained is divided into the number of teams calculated for every return period and according to the different operational times[2] and time factors. The result is the numbers of parcels that every team (two inspectors) will have to inspect in one day under different operational times, but it is not represented in a spatial way.

[2] The operational time is the number of working hours per day of the building inspectors, assumed here in three possible states 8, 10 or 12 hours and while maintaining the total time to carry out the inspection according to the international standards, 72 hours or three days from event of disaster

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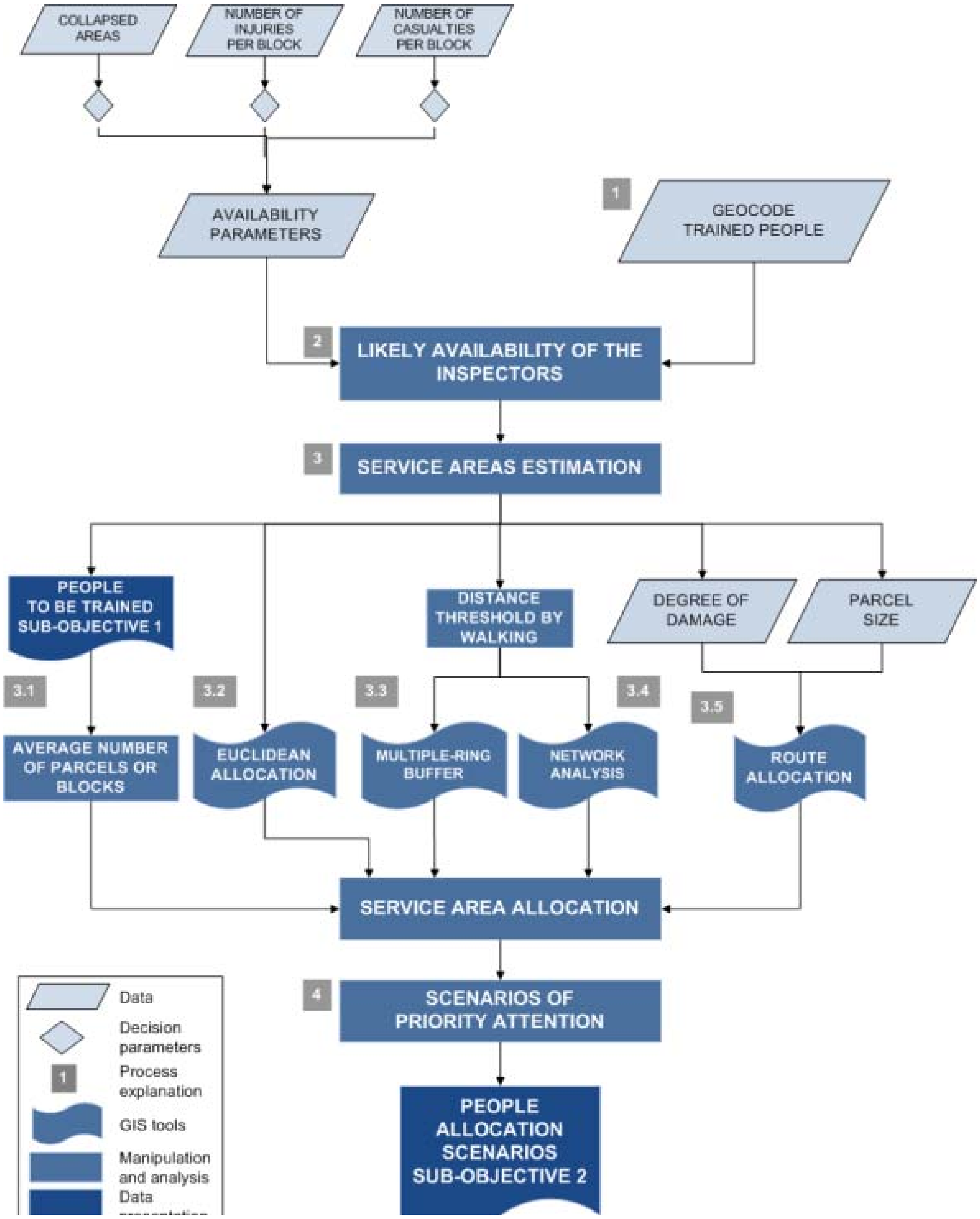

Figure 3-2 Sub-objective 2: Model to allocate trained people.

Euclidean allocation: in this option a nearest source (inspector location) is calculated for each parcel and it could be a starting point to allocate a service areas.

Distance threshold by walking: aim to estimate the service areas, it is compulsory to decide the maximum distance threshold or "the acceptable service distance" (Batanovic et al., 2009) that the inspectors must walk to inspect the farest buildings in their allocated service area; the inspectors have to cover the inspection areas by walking and the maximum travel time must be one hour (origin – destination and destination-origin) as an "acceptable travelling service time" (Batanovic et al., 2009); taking into account the average walking speed in the humans (4 to 5 Km/hr), the idea is to use the value of 5 Km as a maximum threshold distance to fix the boundaries of the service area and divide the service areas per day along the three days based on it as it is explained in table 3-1. Under this concept, two methods were applied: a multi-ring *buffer* or *service area* using *network analysis*.

PERIOD	TOTAL DISTANCE (origin – destination and destination – origin) meters	DISTANCE (origin-destination)	DISTANCE (destination -origin)	TOTAL TRAVEL TIME (origin – destination and destination – origin) minutes
First day	1667	833	833	20
Second day	2500	1250	1250	40
Third day	5000	2500	2500	60

Table 3-1 Walking distance in a service area.

Multi-ring buffer: the distance-to-walk every day could be used as the first approach; or as the only alternative when the data about roads is not available. To estimate the coverage level, it is selected by location the parcels that intersect with the buffers, which shows the covered areas; and then, it is possible to switch the selection to have a view of the uncovered areas.

Network analysis (service area): when the data about roads is existing, the allocation of the service areas can be figured out using *network analysis*, but to observe in a clear way the boundaries of the service areas per day it is important in the polygon generation tab check *Not overlapping* option.

Route allocation: the route allocation is the route of every inspector. The route is designed according to the estimated inspection time that every house may require according to its size or estimated degree of damage, as it can be observed in table 3-2.

DAMAGE DEGREE	INSPECTION TIME minutes
15% - 25%	10
26% - 35%	15
36% - 45%	20
46% - 55%	25
56% - 65%	30

Table 3-2 Required inspection time per parcel according to the degree of damage.

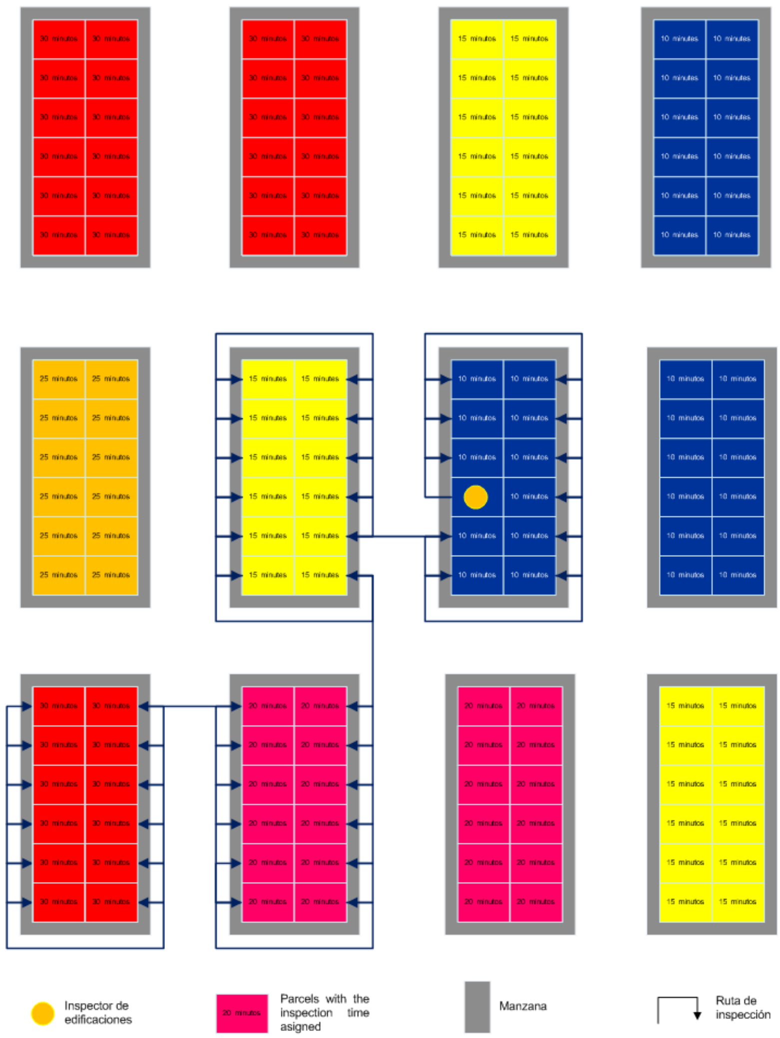

Figure 3-3 Schematic allocation route according to the inspection time (operational time: 12 hours).

The present research develop the method based on the estimated degree of damage. The seismic scenarios estimate a degree of damage per block in each return period and it is possible to make an assumption of the inspection time required per parcel according to this. The path starts at the inspectors' house and when they head off their own house, they will continue in a clock wise direction during the operational time, e.g.: 8, 10 or 12 hours. The inspection time per house included in the route will define the size of the inspection area. The analysis to design the inspector route is based on a *network analysis (the best route)*; the program calculates the route and symbolizes the stops, which are centroids with the attribute of the inspection time; it is possible to know the total inspection time in a day from the attribute table of the route layer, and the same procedure it is done for the next two days. It is necessary reorder the stops, aim to the starting point will be the inspector's house and the order of the stops follow the clock wise logic. A schematic example of a route allocation to one inspector, when the operational time is a period of 12 hours is illustrated on figure 3-3.

The last step is the fourth, display the different priority scenarios. In a rapid building damage survey after an earthquake, some areas in the city must be inspected firstly. The tool of suitability wizard in *Community Viz* is applied to make priority attention analysis, over the areas in the city. To carry out the analysis using this software application, two kinds of layers are necessary: one *suitability layer* and *other layers*. The *suitability layer* is the dynamic layer that contains the features whose suitability or attention priority, it is necessary to be measured. The *other layers* are to measure the attention priority that in this case correspond to proxy indicators as it was done in the research carry out by Benini et al. (2008).

4. CASE STUDY AREA:

The study area was Bogotá D.C., the capital city of Colombia. The city was selected as a case study due to it is located in a medium hazard seismic zone, in a country close to the meeting point of four tectonic plates and included in the "Pacific Ring of Fire".

This city has not been struck by a strong earthquake since 1928 (Unidad de Prevención y Atención de Emergencias - UPES, 1997), which means that there is a high probability of that strong seismic event occurring in the coming years. Therefore, the Major of Bogotá D.C. through DPAE has been working on the preparedness tasks and one of them was the creation of the building inspection group.

The advances in the training process about building damage survey were another reason to select the city as the case study place. This training was done at first by DPAE (2002-2003), and now by the Universidad Distrital (2007) under DPAE.

The work on field consisted mainly on a survey between people trained in both periods to estimate the availability (desirability) to carry out the building inspection in case of an earthquake in the city. At first, the result was 121 available, but later it was incorporated the number of trained people who did not reply to the survey to have a final result of 735 trained people geocoded.

Based on the data about location of the trained people, it will be possible to estimate the respective service areas.

5. RESULTS:

The inspection area contains 675.588 residential parcels. Nevertheless, only the affected parcels with a percentage of damage between 15% and 65% were considered to be inspected. According to this assumption, the number of parcels to be inspected is made up of 106.838 (16%) in the rp of 250 years, 318.945 (47%) in the rp of 500 years and 362.898 (54%) in the rp of 1000 years, as it can be appreciated on figure 4-1.

Firstly, trained people were geocoded using the information of the survey; and then, it was estimated their availability according to the parameters described in the methodology. The result was 712 (97%) trained people likely available, as the lowest value in the worst case. Trained people are spread out over the city with a light concentration in the North – Est as it is illustrated in figure 4-2.

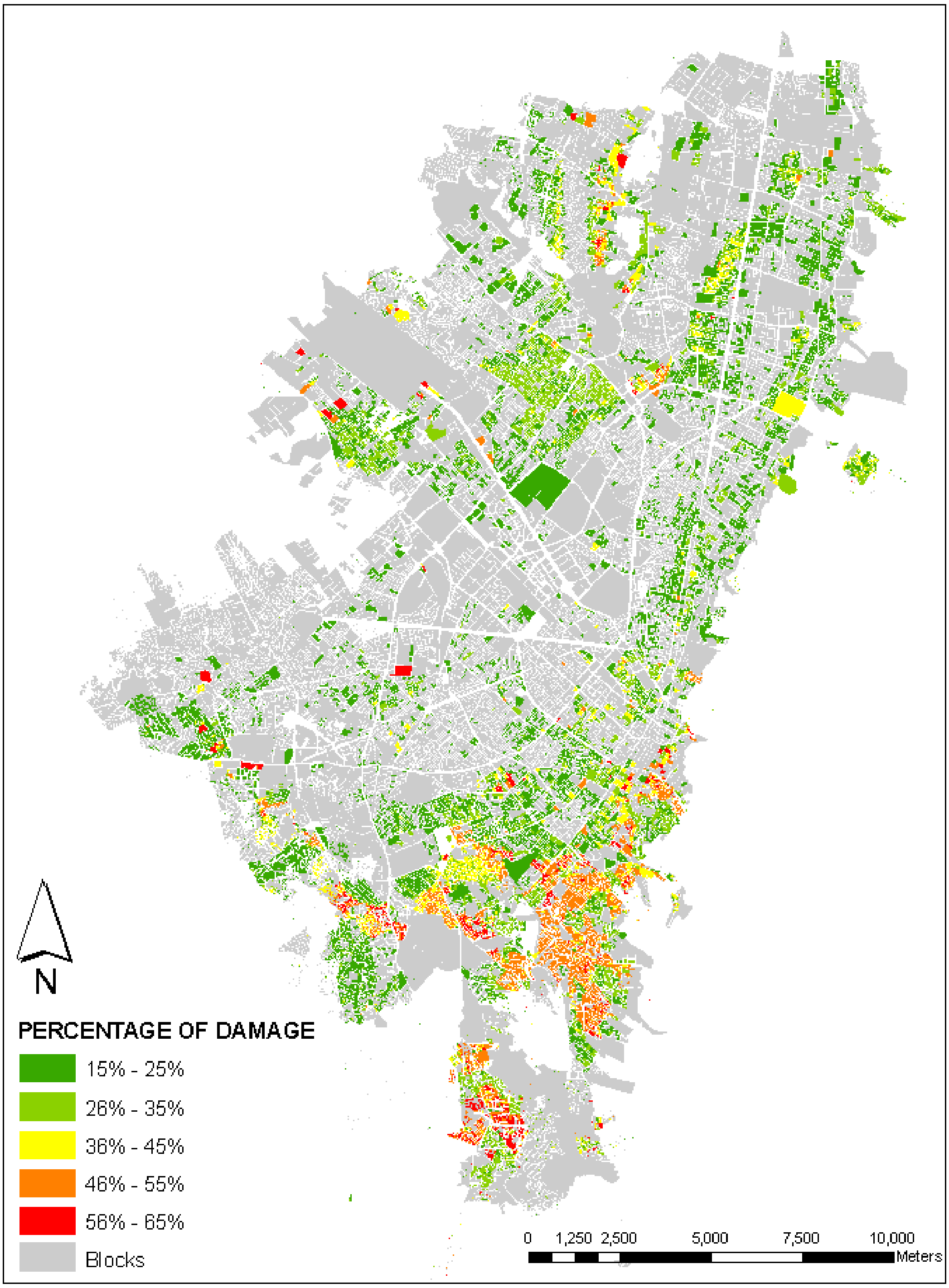

Figure 4-1 Degree of damage in the inspection area for the seismic scenario (RP) 1000 years, when the seismic source is the falla frontal de la cordillera oriental in Bogota D.C., Colombia.

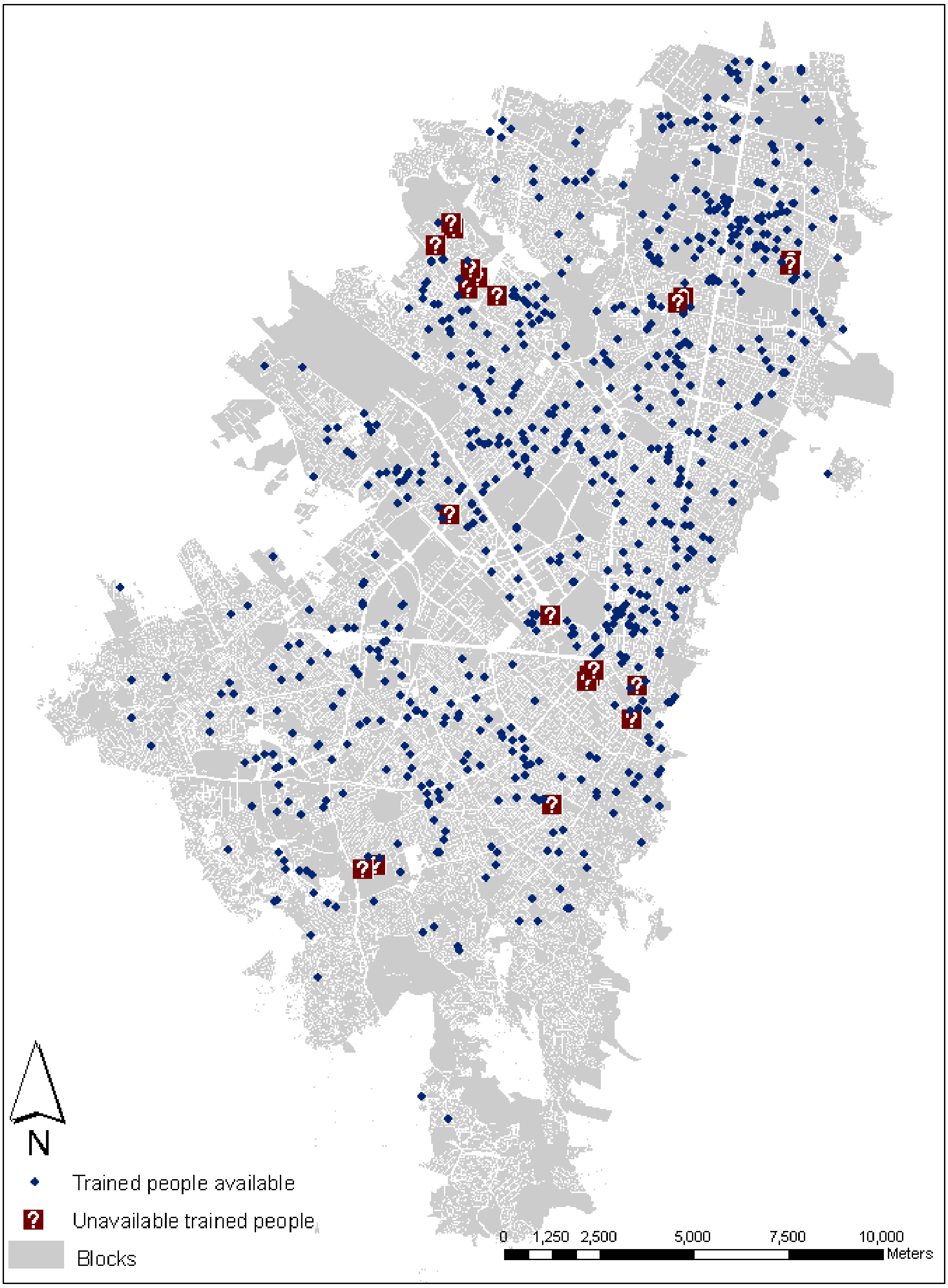

Figure 4-2 Location of trained people available to carry out the building damage survey.

According to the methodology, the next step is to estimate the service areas for the available people to have a view of the likely coverage by using all the methods detailed in the methodology to find their advantages and disadvantages aim to select the method that best fit the requirements.

The *Average number of parcels or blocks to be inspected for a team in one day* is obtained by using the output of the estimation of the number of teams and inspectors required, as it can be seen on table 4-1. However, it is noted that the result of applying this method is not spatial and it must be used to support the other spatial approaches like *route allocation*.

SPACE PARAMETERS			TIME PARAMETERS			7 - OPERATIONAL TIME								
PARCELS TO INSPECT		PARCELS TO INSPECT PER DAY	4 -TIME FACTOR		5 - HOURS	8	10	12	8	10	12	8	10	12
		Parcels/3	min per parcel	Total minutes	min/60	8 - TEAMS NUMBER			PARCELS TO INSPECT PER TEAM IN ONE DAY			BLOCKS TO INSPECT PER TEAM IN ONE DAY		
RP 250	106,838	35,613	10	356,127	5,935	742	594	495	48	60	72	3	4	5
			15	534,190	8,903	1,113	890	742	32	40	48	2	3	3
			20	712,253	11,871	1,484	1,187	989	24	30	36	2	2	2
			25	890,317	14,839	1,855	1,484	1,237	19	24	29	1	2	2
			30	1,068,380	17,806	2,226	1,781	1,484	16	20	24	1	1	2
RP 500	318,945	106,315	10	1,063,150	17,719	2,215	1,772	1,477	48	60	72	3	4	5
			15	1,594,725	26,579	3,322	2,658	2,215	32	40	48	2	3	3
			20	2,126,300	35,438	4,430	3,544	2,953	24	30	36	2	2	2
			25	2,657,875	44,298	5,537	4,430	3,691	19	24	29	1	2	2
			30	3,189,450	53,158	6,645	5,316	4,430	16	20	24	1	1	2
RP 1000	362,898	120,966	10	1,209,660	20,161	2,520	2,016	1,680	48	60	72	3	4	5
			15	1,814,490	30,242	3,780	3,024	2,520	32	40	48	2	3	3
			20	2,419,320	40,322	5,040	4,032	3,360	24	30	36	2	2	2
			25	3,024,150	50,403	6,300	5,040	4,200	19	24	29	1	2	2
			30	3,628,980	60,483	7,560	6,048	5,040	16	20	24	1	1	2
		AVERAGE	20	1752624	29210	3651	365	30	28	35	42	2	2	3

Table 4-1 Estimation of average number of parcels or blocks to be inspected for a team in one day.

The use of the *euclidean allocation* method has the advantage that every trained person has an area allocated to inspect, the drawback is that the resulting service areas do not have an equal size and the road data is not considered, hence the accuracy level is low. The coverage estimated for all the return periods show an average of 95% of parcels that could be inspected. The result of the application of this method can be seen on figure 4-3.

Multi-ring buffer method also allocate service areas to the 100% of the trained people and it is the first approach to estimate the coverage based on the maximum threshold *distance-to-walk* per day; nevertheless, the disadvantage of this method is that the most of the times boundaries between the service areas are not clear, even using any of the two dissolve options (*all* or *none*); the problem with the merge and overlap is that there is a high risk that some parcels will be allocated twice and hence re-visited, making a bad use of the likely scarce resources (building inspectors), in the real time. Another drawback about using this method is that the *distance-to-*

walk is measured in a straight line and not taking into account the road network, which also decreases the accuracy level. The level of coverage in the city under this method presents an average of 95% of the parcels that could be inspected in the three days. The result of allocation and coverage after using this method can be observed on figure 4-4.

The use of *network analysis* **(**service areas) method to allocate the service area is more appropriate than the last methods, because it considers the distance-to-walk per day based on the road network and this tool allows knowing who does not have any service area allocated because the person is in the middle of other service areas. However, the level of accuracy is not enough because they do not take into account the degree of damage or the inputs from the first model about the numbers of parcels that must be inspected every day to cover all the parcels in every seismic scenario, which is a constant disadvantage also in the methods presented before. The coverage by using this method put forward an average of 89% of parcels that could be likely inspected in the city. The result of allocation and coverage after using this method can be observed on figure 4-5.

The *route allocation* per day also can be the first approach, but the limitations are the uncertainty in the inspection times, and due to the irregularity in the number of parcels per block, it is necessary to estimate the route allocation to every inspector one by one. The *route allocation* could be designed estimating the inspection time based on the degree of damage, as it is done in the present research, taking the advantage that there is a degree of damage already calculated; or based on the size of the built-up area, its estimations can be calibrated in both cases through a simulation exercises. There is no estimation of the coverage for the whole city, as the procedure requires long computation time that are beyond of the scope of this research. An example of the implementation of this method can be appreciated on figure 4-6.

Nevertheless, because of the level of the detail in this last method, it could offer more realistic results in terms of likely coverage. Therefore, to extrapolate this methodology to the rest of the city, it has to be combined with the *buffer analysis* method, due to it simulate in a proper way the probable size of the inspection area. This time, the results show an opposite result related to the coverage with an average of just 9% of parcels than could be inspected in all the return periods. The result can be appreciated on figure 4-7.

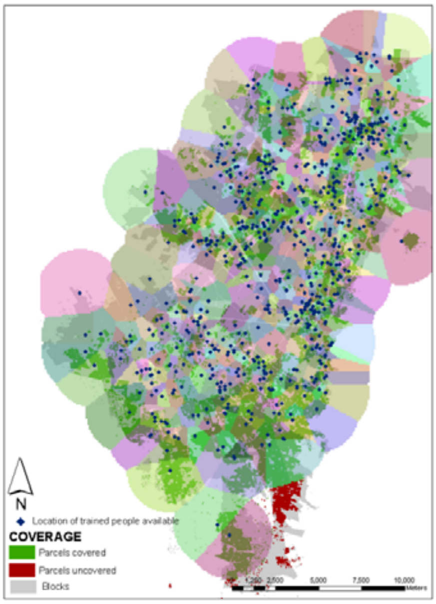

Figure 4-3 Estimation of service areas based on euclidean allocation method in the rp 1000 years. Seismic source: falla frontal de la cordillera oriental.

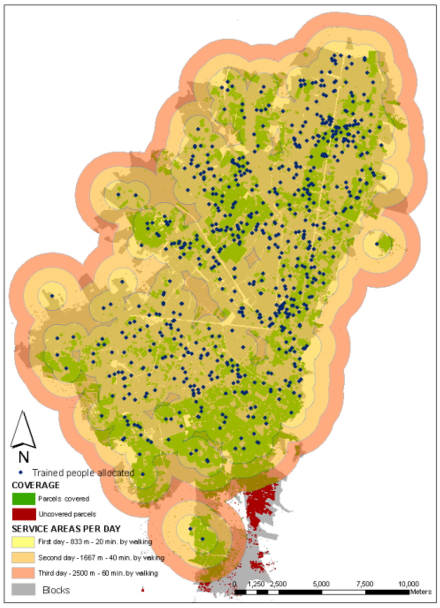

Figure 4-4 Estimation of service areas based on multiple ring buffer in the rp 1000 years. Seismic source: falla frontal de la cordillera oriental.

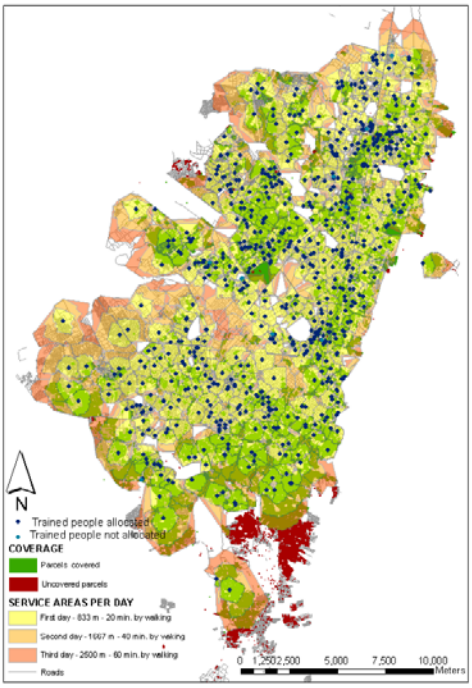

Figure 4-5 Estimation of service areas based on network analysis in the rp 1000 years. Seismic source: falla frontal de la cordillera oriental.

Figure 4-6 Estimation of one service area per day according to the inspection time. Seismic source: falla frontal de la cordillera oriental.

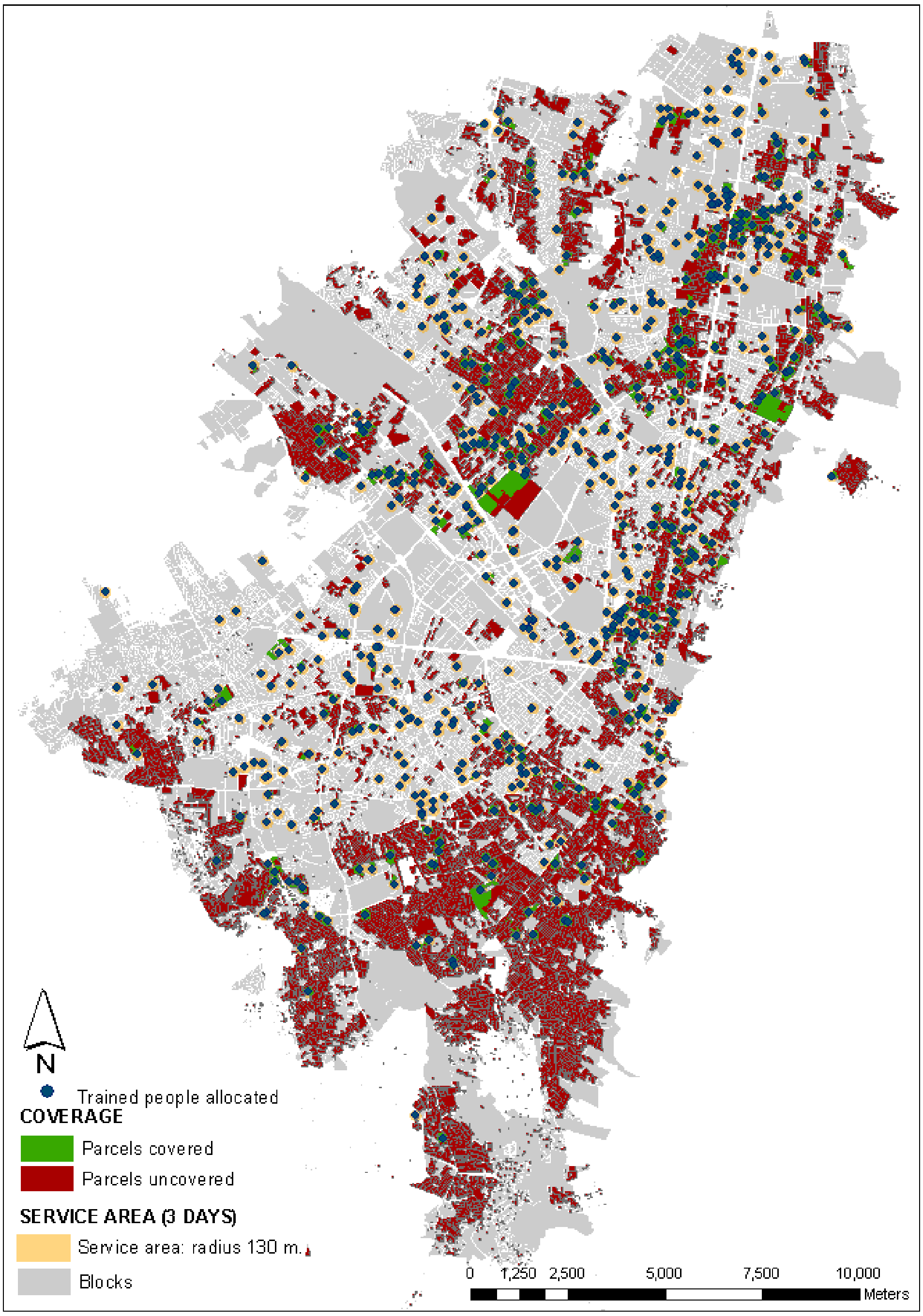

Figure 4-7 Estimation of service areas based on the combination of *route allocation* and *buffer analysis* method in the RP 1000 years. Seismic source: falla frontal de la cordillera oriental.

According to the methodology, it is necessary to develop priority attention scenarios in order to make an efficient use of the resources. Priority attention scenarios allow the emergency response planners to know where the people must be trained and to the decision-makers, where the people must be sent them firstly. To develop the scenarios, it is necessary to follow the fourth step in the second model about display the different priority scenarios.

The *suitability layer* in the present research is the whole city and the *other layers* or factors considered were population density, degree of damage, built-up density, industrial areas and areas with hazard by landslides, due to the possibility of secondary effects after the earthquake like fires or landslides, and finally the location of trained people. These factors are weighted in order to decide where the free inspectors must be sent them.

Four scenarios with different scores were developed in the entire research. However, in the present document just the scenario where population density and landslides have the highest scores is presented, due to Bogotá D.C. is a city prone to landslides and also because the spatial results do not show any considerable change, in the other scenarios. The weights given are shown in figures 4-8 and the spatial result is displayed on figure 4-9.

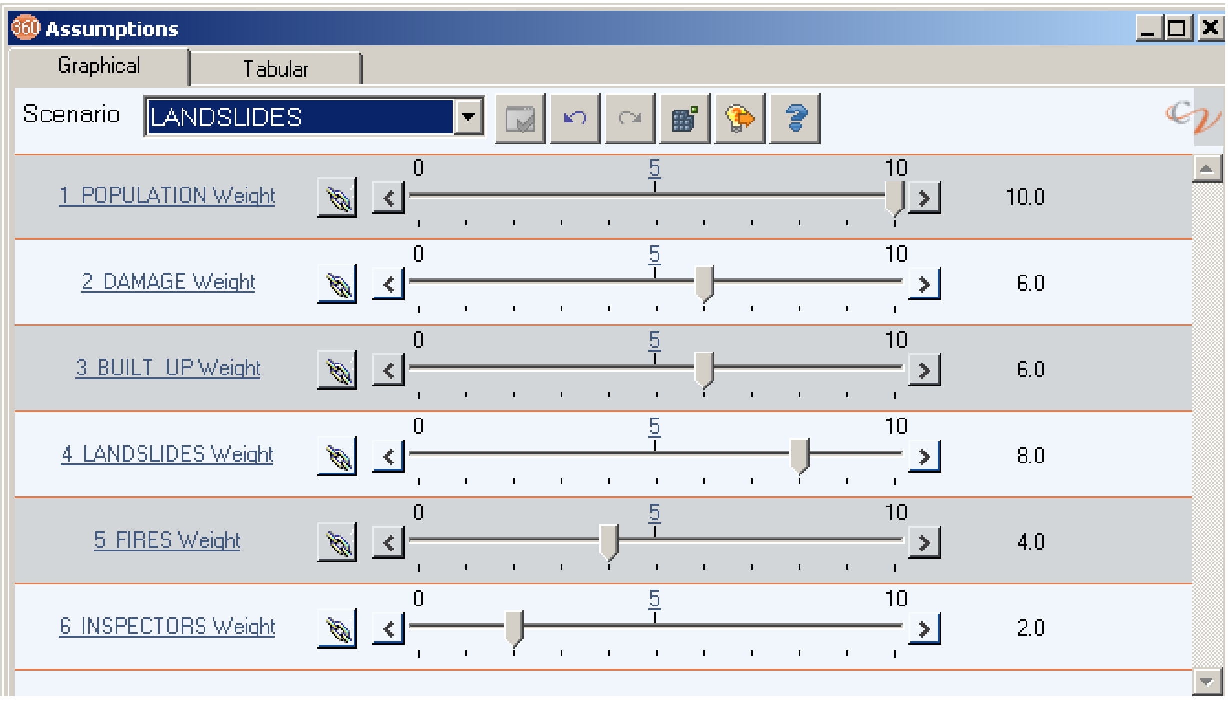

Figure 4-8 Weights given to carry out the attention priority analysis

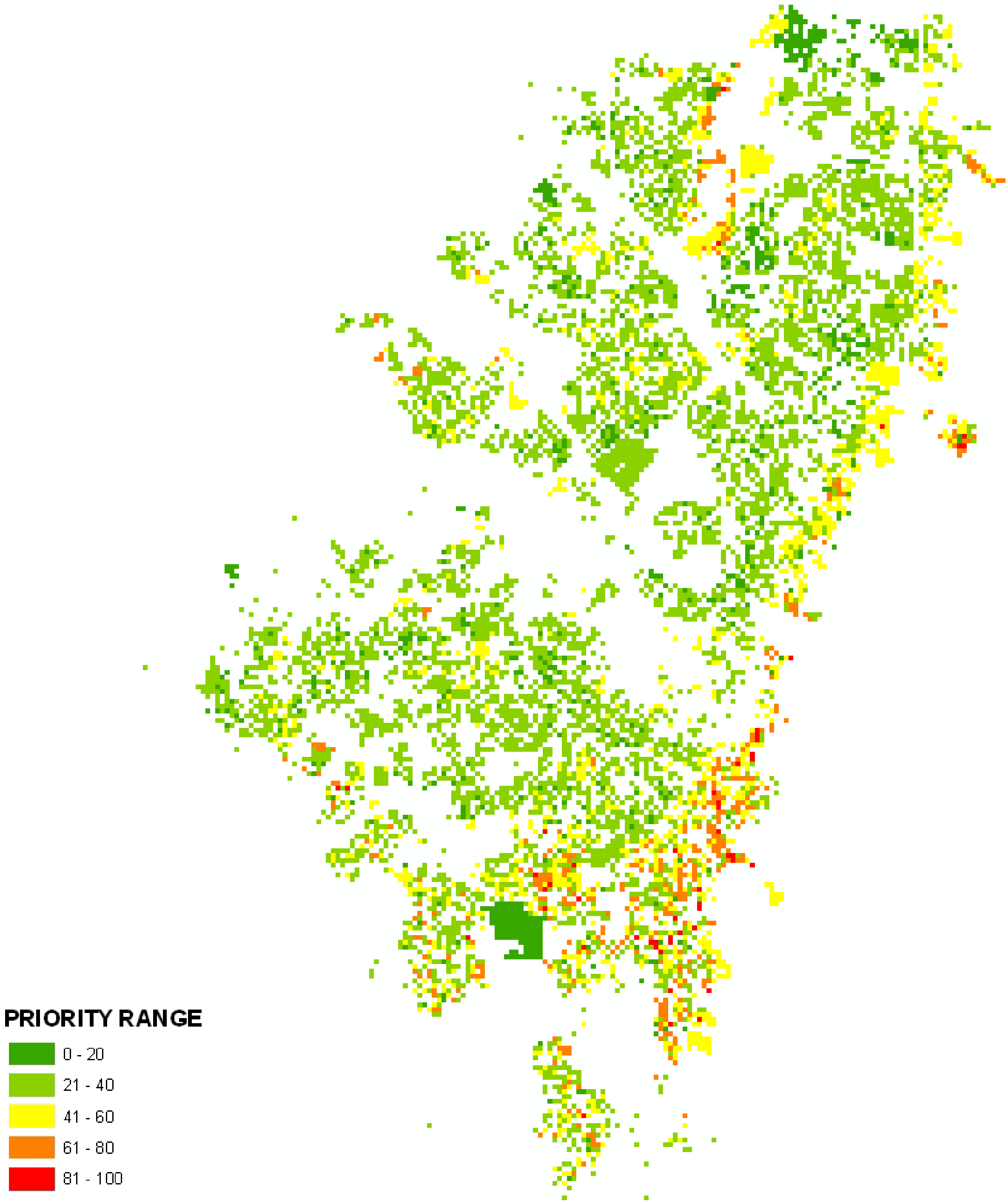

Figure 4-9 Attention priority scenarios for Bogotá D.C.

It is possible to observe in the last map that the South East of Bogotá D.C. shows the highest scores in the priority range, similar to the results in the other scenarios with different scores to the factors.

6. DISCUSSION, CONCLUSSIONS AND RECOMMENDATIONS

The idea of the survey carried out for this research is not only provide insights into the spatial distribution of the trained people and the estimated coverage, but also the training conditions that must be improved.

Trained people in the survey who expressed their availability was almost 100%, even in the earlier group trained between 2002 and 2003, but a few of them remembered the content of the lectures or kept the material given for that time. This result is not suitable, due to the idea of the survey is to have a standard criteria to determine the safety condition of the building inspected.

Taking into account the mentioned point, the survey carried out on fieldwork to inference about availability must be split to differentiate between desirability and capability, because trained people who wants to participate in the survey; likely, may not remember the procedure, nor the criteria assessment to establish the habitability of a building, as it was shown by the results of the survey.

On the basis of the data and maps in Bogotá D.C. as a case study city, trained people included in the sampling (surveyed and not surveyed) are spread out over the city and it is possible to predict a high coverage in the North, and acceptable in the south, but some deficit of coverage in the South-Est.

In real time, expressed availability and effective presence must be items to be measured, and later they could be used to calibrate the model in the part related to the estimation of the likely availability of personnel; this is necessary in order to know the percentage of trained people who having expressed their availability before the event, effectively carried out the inspection task.

The accuracy of the results rather than depend on the right assumptions, they depend on the accuracy of the data, from these are based. Due to the last, it is important to invest money in seismic hazard research and monitoring, beside to have updated census, cadastral data and vulnerability analysis in the most disaggregate way as it is possible; because, it will reduce the uncertainty in the loss estimation and the preparedness planification.

Cities with seismic hazard should train people permanently about building damage survey and the idea to have their location, is to see where there will be coverage deficit. This analysis allows to give training priority to people located in those areas. A kind of survey, as it was done on fieldwork must be done every year or at least every three years to have a view of the number of trained people available and to know how many people else must be trained. Additionally, there must be a website in order that when the inspectors change their personal information, they can update this data by themselve. In this way, it is possible to have a spatial distribution and hence the service areas updated all the time.

The data and the preparedness level of the city will define the method to allocate the service areas to the inspectors. The compulsory inputs in the analysis are the location of the trained people, the parcels data, and the affected areas. The location of the trained people must be updated as frequent as possible in the pre-disaster phase, and according to the report of availability in response time after the earthquake. The information about the affected areas in the present research was taken from the loss estimation scenarios, but in real time the information will come from reports made by phone calls, the observations of the building inspectors, aerial photography or videos and the spatial data will be obtained through mechanism as *International Charter on space and major disasters*[3].

The data about roads and their connectivity will increase the accuracy for efficient allocation of the service areas. If the level of the service area estimation through route allocation is achieved it will increase the effectiveness of the inspection because owners can beforehand meet the inspectors who will be in charge to check their houses after the earthquake, avoiding security problems.

The importance of the maps with the inspection times according to the damage degree or the size of the parcels could display a view of where the problems with high range of times could appear, and therefore is necessary to train more people in the preparedness phase or to send more people in the response time because the size of service areas will decrease. The size of the service areas are inversely related to the inspection times per parcel.

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[3] The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property.(CNES, 2008)

The estimation of the service areas allow the emergency response planners to know the covered and the uncovered areas and consider the options to figure out how to inspect those areas with trained people who does not have any service area allocated. Four of the five methods used to allocate the inspection areas show a high coverage in the case study city, with a deficit in the South- East, but just making the route allocation to every inspector is possible to estimate a more realistic percentage of parcels that can be inspected in the period of the rapid building damage survey. The route allocation shows in a more accurate approach the service area of every inspector and to have a better view of the covered and the uncovered areas in the city.

The route allocation per day also could be the first approach but the limitation is the uncertainty in the inspection times, for that reason is better to take into account the other methods.

Not allocated people must be sent to the South-East of the city according to the priority criteria that emergency response planners or decision makers define, but the transport modes and analysis accessibility must be done to plan how to reach these points. It is necessary to look for people to be trained in the South –East of the city or train people living there to recognize serious damages in the structure of their houses, in order that they will be able to decide evacuate or not, before a trained people can inspect their houses. However, not only people in uncovered areas must be trained in recognizes serious damage in the houses structure, but also in the areas where the coverage is more likely because it increase the effectiveness of the objective of the rapid building damage survey that it is save lives. The cities with seismic hazard and interested in develop this kind of model have to do their best to reach this stage.

The route allocation could be designed as in the present research estimating the inspection time based on the damage degree or the size of the built-up area, and this estimation can be calibrated through a simulation exercise. The average between the inspection times estimated in the analysis and the inspection time measured in the exercise might be used to adjust the service area and also as a kind of sensitivity analysis, until a validation can be done.

The research also tested the viability of using *CommunityViz* as spatial planning support system, in the process to plan the emergency response. This software application was originally designed to develop scenarios aimed at taking decisions about land-use planning. In the present research, the usefulness was on demarcating areas that need priority attention through the use of proxy indicators. Both activities, land-use planning and emergency response planning are based on a group of factors that must be weighted, in order to take the best decision. The final result was useful in spite of the technical limitations like the need to convert the all the layers to raster data because of the computation time, then the subsequent problems with the projection.

The use of CommunityViz to establish priority areas is feasible if the data about priority attention criteria is available and enough updated. The priority attention criteria must be decided in the preparedness phase by the entities involved in the emergency response task.

Since CommunityViz is a spatial planning support system designed to facilitate land use planning process, its use as a tool in the emergency response planning process is also feasible and helpful. The priority areas in all the scenarios are located in the South East, but the differences in priorities are more noticeable in a big scale. The priority attention analysis in the uncovered areas shows that the areas with highest priority are in the most of the cases the same and the problem it is that they match in the most of the times with the uncovered areas, which is a dilemma for the emergency response planners and the decision makers. Therefore, it is necessary to keep in mind the recommendations described in the last paragraphs about train more people in those areas, train the community and plan the mobilization of non-allocated people there.

Concluding, in spite of the results presented in the present research have a high degree of uncertainty, they are useful to plan the emergency response related to damage assessment and the model can be replicated in whatever city interested in to be prepared for an earthquake.

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REFERENCES

Batanovic, V., Petrovic, D., & Petrovic, R. (2009). Fuzzy logic based algorithms for maximum covering location problems. *Information Sciences, 179*(1-2), 120-129.

Bendimerad, F. (2001). Loss estimation: a powerful tool for risk assessment and mitigation. *Soil Dynamics and Earthquake Engineering, 21*(5), 467-472.

Benini, A., & Conley, C. (2007). Rapid humanitarian assessments and rationality: a value-of-information study from Iraq, 2003-04. *Disasters, 31*(1), 29-48.

Benini, A., Conley, C., Dittemore, B., & Waksman, Z. (2008). Survivor needs or logistical convenience? Factors shaping decisions to deliver relief to earthquake-affected communities, Pakistan 2005–06. *Disasters, 9999*(9999).

CEDERI, U. (2005). *Informe Final, Escenarios de Riesgo y Perdidas por Terremoto para Bogotá D.C.* Bogotá D.C: DPAE,Alcaldía Mayor de Bogotá D.C.

Chiu, Y.-C., & Zheng, H. (2007). Real-time mobilization decisions for multi-priority emergency response resources and evacuation groups: Model formulation and solution. *Transportation Research Part E: Logistics and Transportation Review, 43*(6), 710-736.

CNES, E. a. (2008, December 19, 2008). International Charter on space and major disasters. Retrieved May 31, 2009, 2009, from http://www.disasterscharter.org/about_s.html

Contreras, D. (2002). *Estrategia Metodológica para la conformación de grupos inspectores de edificaciones después de un sismo en Bogotá D.C.*, Universidad de Los Andes, Bogota D.C.

Debarati Guha-Sapir, M. F. L. (1986). Information systems and needs assessment in natural disasters: An approach for better disaster relief management. *Disasters, 10*(3), 232-237.

Fiedrich, F., Gehbauer, F., & Rickers, U. (2000). Optimized resource allocation for emergency response after earthquake disasters. *Safety Science, 35*(1-3), 41-57.

Fuad Aleskerov, A. I. S. A. T. H. L. A. G. A. (2005). A cluster-based decision support system for estimating earthquake damage and casualties. *Disasters, 29*(3), 255-276.

Hoard, M., Homer, J., Manley, W., Furbee, P., Haque, A., & Helmkamp, J. (2005). Systems modeling in support of evidence-based disaster planning for rural areas. *International Journal of Hygiene and Environmental Health, 208*(1-2), 117-125.

Lee, J. Y. (2007). A three-dimensional navigable data model to support emergency response in microspatial built-environments. *ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS, 97*(3), 512-529.

Melanie, G. (2004). Where to Go? Strategic Modelling of Access to Emergency Shelters in Mozambique. *Disaster, 28*(1), 82-97.

Ozdamar, L., Ekinci, E., & Kucukyazici, B. (2004). Emergency logistics planning in natural disasters. *Annals of Operations Research, 129*(1-4), 217-245.

Pacione, M. (2005). *Urban geography : a global perspective* (Second edition ed.). London etc.: Routledge.

Perry, R. W., & Lindell, M. K. (2003). Preparedness for Emergency Response: Guidelines for the Emergency Planning Process. *Disasters, 27*(4), 336-350.

Unidad de Prevención y Atención de Emergencias - UPES, I. C. d. M. y. G.-I., Universidad de Los Andes. (1997). *Estudio de Microzonificacion Sismica de Santafe de Bogotá D.C.* Retrieved. from.

Wallace, W. A., & Balogh, F. D. (1985). Decision Support Systems for Disaster Management. *Public Administration Review, 45*, 134-146.

Yan, S., & Shih, Y.-L. (2007). A time-space network model for work team scheduling after a major disaster. *Journal of the chinese institute of engineers, 30* (1), 63-75